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Chapter 1

Basic Brain Facts

With our new knowledge of the brain, we are just dimly beginning to realize that we can now understand humans, including ourselves, as never before, and that this is the greatest advance of the century, and quite possibly the most significant in all human history.

—Leslie A. Hart,
Human Brain and Human Learning

***Chapter Highlights**:* This chapter introduces some of the basic structures of the human brain and their functions. It explores the growth of the young brain and some of the environmental factors that influence its development into adolescence. Whether the brain of today's student is compatible with today's schools is also discussed.

The adult human brain is a wet, fragile mass that weighs a little over three pounds. It is about the size of a small grapefruit, is shaped like a walnut, and can fit in the palm of your hand. Cradled in the skull and surrounded by protective membranes, it is poised at the top of the spinal column. The brain works ceaselessly, even when we are asleep. Although it represents only about 2 percent of our body weight, it consumes nearly 20 percent of our calories! The more we think, the more calories we burn. Perhaps this can be a new diet fad, and we could modify Descartes' famous quotation from "I think, therefore I am" to "I think, therefore I'm thin"!

Through the centuries, surveyors of the brain have examined every cerebral feature, sprinkling the landscape with Latin and Greek names to describe what they saw. They analyzed structures and

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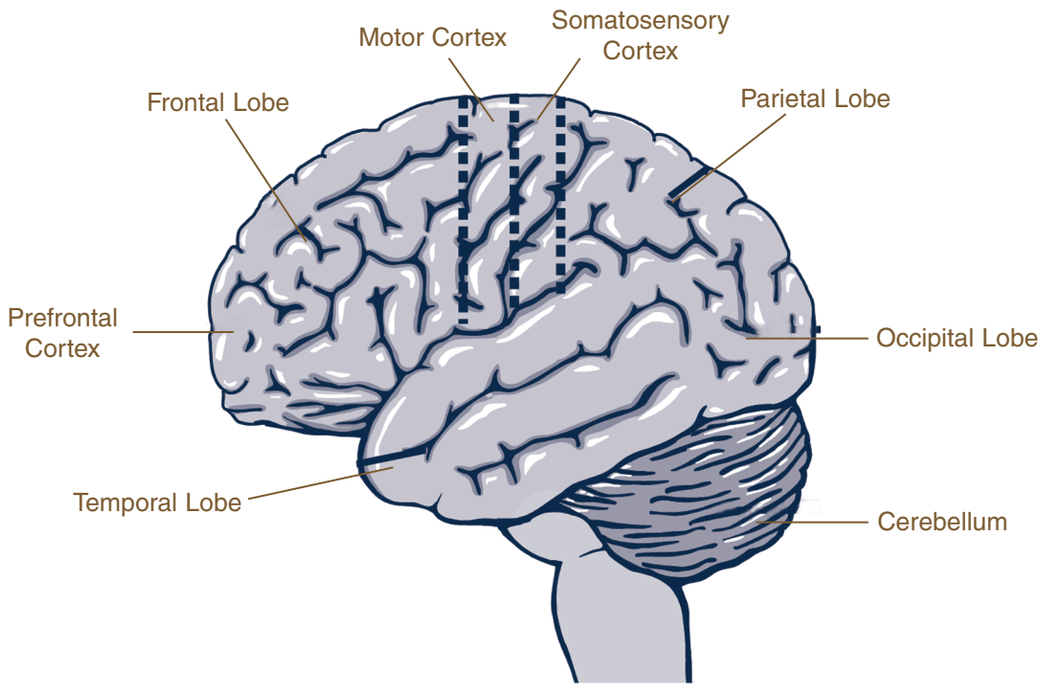

Figure 1.1 The major exterior regions of the brain.

functions and sought concepts to explain their observations. One early concept divided the brain by location—forebrain, midbrain, and hindbrain. Another, proposed by Paul MacLean in the 1960s, described the triune brain according to three stages of evolution: reptilian (brain stem), paleo-mammalian (limbic area), and mammalian (frontal lobes).

For our purposes, we will take a look at major parts of the outside of the brain (Figure 1.1). We will then look at the inside of the brain and divide it into three parts on the basis of their general functions: the brainstem, limbic system, and cerebrum (Figure 1.2). We will also examine the structure of the brain's nerve cells, called *neurons*.

SOME EXTERIOR PARTS OF THE BRAIN

Lobes of the Brain

Although the minor wrinkles are unique in each brain, several major wrinkles and folds are common to all brains. These folds form a set of four lobes in each hemisphere. Each lobe tends to specialize for certain functions.

Frontal Lobes. At the front of the brain are the *frontal lobes*, and the part lying just behind the forehead is called the *prefrontal cortex.* These lobes deal with planning and thinking. They comprise the rational and executive control center of the brain, monitoring higher-order thinking, directing problem solving, and regulating the excesses of the emotional system. The frontal lobe

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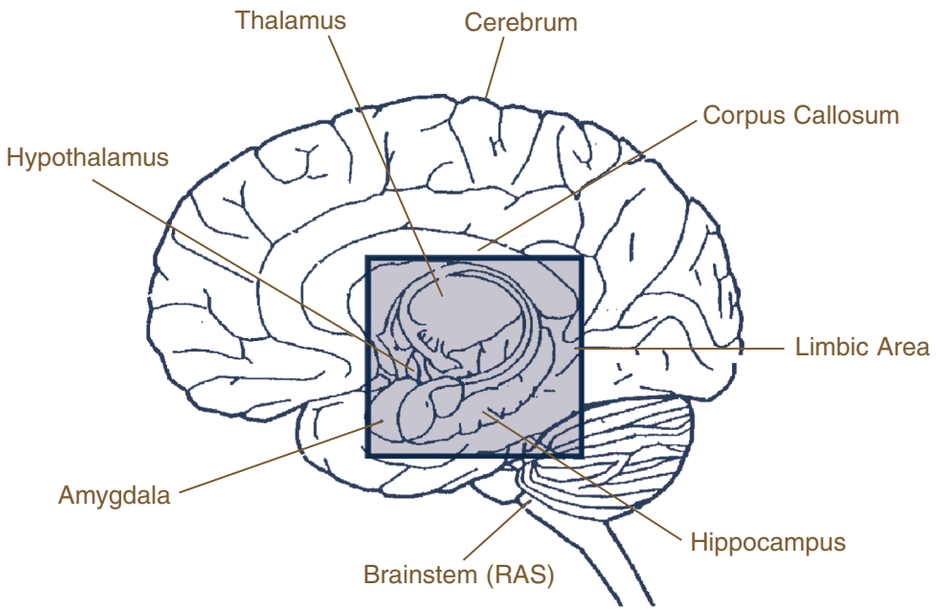

Figure 1.2 A cross section of the human brain.

also contains our self-will area—what some might call our personality. Trauma to the frontal lobe can cause dramatic—and sometimes permanent—behavior and personality changes. Because most of the working memory is located here, it is the area where focus occurs (Smith & Jonides, 1999). The frontal lobe matures slowly. MRI studies of post-adolescents reveal that the frontal lobe continues to mature into early adulthood. Thus, the capability of the frontal lobe to control the excesses of the emotional system is not fully operational during adolescence (Sowell, Thompson, Holmes, Jernigan, & Toga, 1999; Goldberg, 2001). This is one important reason why adolescents are more likely than adults to submit to their emotions and resort to high-risk behavior.

Because the rational system matures slowly in adolescents, they are more likely to submit to their emotions.

Temporal Lobes. Above the ears rest the *temporal lobes*, which deal with sound, music, face and object recognition, and some parts of long-term memory. They also house the speech centers, although this is usually on the left side only.

Occipital Lobes. At the back are the paired *occipital lobes*, which are used almost exclusively for visual processing.

Parietal Lobes. Near the top are the *parietal lobes*, which deal mainly with spatial orientation, calculation, and certain types of recognition.

Motor Cortex and Somatosensory Cortex

Between the parietal and frontal lobes are two bands across the top of the brain from ear to ear. The band closer to the front is the *motor cortex*. This strip controls body movement and, as we will

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learn later, works with the cerebellum to coordinate the learning of motor skills. Just behind the motor cortex, at the beginning of the parietal lobe, is the *somatosensory cortex,* which processes touch signals received from various parts of the body.

SOME INTERIOR PARTS OF THE BRAIN

Brainstem

The brainstem is the oldest and deepest area of the brain. It is often referred to as the reptilian brain because it resembles the entire brain of a reptile. Of the 12 body nerves that go to the brain, 11 end in the brainstem (the olfactory nerve—for smell—goes directly to the limbic system, an evolutionary artifact). Here is where vital body functions, such as heartbeat, respiration, body temperature, and digestion, are monitored and controlled. The brainstem also houses the reticular activating system (RAS), responsible for the brain's alertness and about which more will be explained in the next chapter.

The Limbic System

Nestled above the brainstem and below the cerebrum lies a collection of structures commonly referred to as the limbic system and sometimes called the old mammalian brain. Many researchers now caution that viewing the limbic system as a separate functional entity is outdated because all of its components interact with many other areas of the brain.

Most of the structures in the limbic system are duplicated in each hemisphere of the brain. These structures carry out a number of different functions including the generation of emotions and processing emotional memories. Its placement between the cerebrum and the brainstem permits the interplay of emotion and reason.

Four parts of the limbic system are important to learning and memory. They are:

The Thalamus. All incoming sensory information (except smell) goes first to the thalamus (Greek for "inner chamber"). From here it is directed to other parts of the brain for additional processing. The cerebrum and cerebellum also send signals to the thalamus, thus involving it in many cognitive activities.

The Hypothalamus. Nestled just below the thalamus is the hypothalamus. While the thalamus monitors information coming in from the outside, the hypothalamus monitors the internal systems to maintain the normal state of the body (called *homeostasis*). By controlling the release of a variety of hormones, it moderates numerous body functions, including sleep, food intake, and liquid intake. If body systems slip out of balance, it is difficult for the individual to concentrate on cognitive processing of curriculum material.

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The Hippocampus. Located near the base of the limbic area is the hippocampus (the Greek word for "seahorse," because of its shape). It plays a major role in consolidating learning and in converting information from working memory via electrical signals to the long-term storage regions, a process that may take days to months. It constantly checks information relayed to working memory and compares it to stored experiences. This process is essential for the creation of meaning.

Its role was first revealed by patients whose hippocampus was damaged or removed because of disease. These patients could remember everything that happened before the operation, but not afterward. If they were introduced to you today, you would be a stranger to them tomorrow. Because they can remember information for only a few minutes, they can read the same article repeatedly and believe on each occasion that it is the first time they have read it. Brain scans have confirmed the role of the hippocampus in permanent memory storage. Alzheimer's disease progressively destroys neurons in the hippocampus, resulting in memory loss.

Recent studies of brain-damaged patients have revealed that although the hippocampus plays an important role in the recall of facts, objects, and places, it does not seem to play much of a role in the recall of long-term personal memories (Lieberman, 2005).

The Amygdala. Attached to the end of the hippocampus is the amygdala (Greek for "almond"). This structure plays an important role in emotions, especially fear. It regulates the individual's interactions with the environment than can affect survival, such as whether to attack, escape, mate, or eat.

Because of its proximity to the hippocampus and its activity on PET scans, researchers believe that the amygdala encodes an emotional message, if one is present, whenever a memory is tagged for long-term storage. It is not known at this time whether the emotional memories themselves are actually stored in the amygdala. One possibility is that the emotional component of a memory is stored in the amygdala while other cognitive components (names, dates, etc.) are stored elsewhere (Squire & Kandel, 1999). The emotional component is recalled whenever the memory is recalled. This explains why people recalling a strong emotional memory will often experience those emotions again. The interactions between the amygdala and the hippocampus ensure that we remember for a long time those events that are important and emotional.

Teachers, of course, hope that their students will permanently remember what was taught. Therefore, it is intriguing to realize that the two structures in the brain mainly responsible for long-term remembering are located in the *emotional* area of the brain. Understanding the connection between emotions and cognitive learning and memory will be discussed in later chapters.

Test Question No. 1: The structures responsible for deciding what gets stored in long-term memory are located in the brain's rational system.

Answer: False. These structures are located in the emotional (limbic) system.

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Cerebrum

A soft jellylike mass, the cerebrum is the largest area, representing nearly 80 percent of the brain by weight. Its surface is pale gray, wrinkled, and marked by furrows called fissures. One large fissure runs from front to back and divides the cerebrum into two halves, called the *cerebral hemispheres*. For some still unexplained reason, the nerves from the left side of the body cross over to the right hemisphere, and those from the right side of the body cross to the left hemisphere. The two hemispheres are connected by a thick cable of over 250 million nerve fibers called the *corpus callosum* (Latin for "large body"). The hemispheres use this bridge to communicate with each other and coordinate activities.

The hemispheres are covered by a thin but tough laminated *cortex* (meaning "tree bark"), rich in cells, that is about 1/10th of an inch thick and, because of its folds, has a surface area of about two square feet. That is about the size of a large dinner napkin. The cortex is composed of six layers of cells meshed in about 10,000 miles of connecting fibers per cubic inch! Here is where most of the action takes place. Thinking, memory, speech, and muscular movement are controlled by areas in the cerebrum. The cortex is often referred to as the brain's gray matter.

The neurons in the thin cortex form columns whose branches extend down through the cortical layer into a dense web below known as the white matter. Here, neurons connect with each other to form vast arrays of neural networks that carry out specific functions.

Cerebellum

The cerebellum (Latin for "little brain") is a two-hemisphere structure located just below the rear part of the cerebrum, right behind the brainstem. Representing about 11 percent of the brain's weight, it is a deeply folded and highly organized structure containing more neurons than all of the rest of the brain put together. The surface area of the entire cerebellum is about the same as that of one of the cerebral hemispheres.

This area coordinates movement. Because the cerebellum monitors impulses from nerve endings in the muscles, it is important in the performance and timing of complex motor tasks. It modifies and coordinates commands to swing a golf club, smooth a dancer's footsteps, and allow a hand to bring a cup to the lips without spilling its contents. The cerebellum may also store the memory of automated movements, such as touch-typing and tying a shoelace. Through such automation, performance can be improved as the sequences of movements can be made with greater speed, greater accuracy, and less effort. The cerebellum also is known to be involved in the mental rehearsal of motor tasks, which also can improve performance and make it more skilled. A person whose cerebellum is damaged slows down and simplifies movement, and would have difficulty with finely-tuned motion, such as catching a ball, or completing a handshake.

Recent studies indicate that the role of the cerebellum has been underestimated. Researchers now believe that it also acts as a support structure in cognitive processing by coordinating and fine-tuning our thoughts, emotions, senses (especially touch), and memories. Because the cerebellum is connected also to regions of the brain that perform mental and sensory tasks, it can perform these skills automatically, without conscious attention to detail. This allows the conscious part of the

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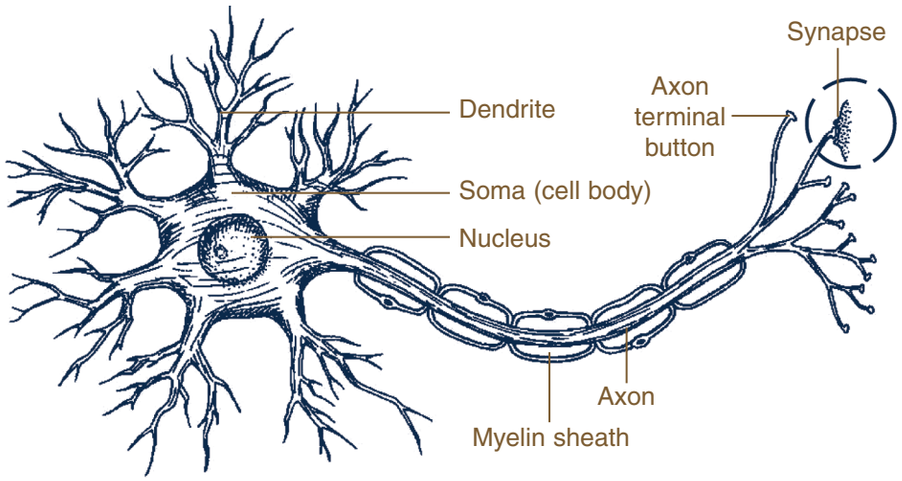

Figure 1.3 Neurons transmit signals along an axon and across the synapse (in dashed circle) to the dendrites of a neighboring cell. The myelin sheath protects the axon and increases the speed of transmission.

brain the freedom to attend to other mental activities, thus enlarging its cognitive scope. Such enlargement of human capabilities is attributable in no small part to the cerebellum and its contribution to the automation of numerous mental activities.

Brain Cells

The brain is composed of a trillion cells of at least two known types, nerve cells and glial cells. The nerve cells are called *neurons* and represent about one-tenth of the total—roughly 100 billion. Most of the cells are *glial* (Greek for "glue") cells that hold the neurons together and act as filters to keep harmful substances out of the neurons. Very recent studies indicate that some glial cells, called *astrocytes*, have a role in regulating the rate of neuron signaling. By attaching themselves to blood vessels, astrocytes also serve to form the blood-brain barrier, which plays an important role in protecting brain cells from blood-borne substances that could disrupt cellular activity.

The neurons are the functioning core for the brain and the entire nervous system. Neurons come in different sizes, but the body of each brain neuron is about 1/100th the size of the period at the end of this sentence. Unlike other cells, the neuron (see Figure 1.3) has tens of thousands of branches emerging from its core, called *dendrites* (from the Greek word for "tree"). The dendrites receive electrical impulses from other neurons and transmit them along a long fiber, called the *axon* (Greek for "axis"). There is normally only one axon per neuron. A layer called the *myelin sheath* surrounds each axon. The sheath insulates the axon from the other cells and increases the speed of impulse transmission. This impulse travels along the neurons through an electrochemical process and can move through the entire length of a 6-foot adult in 2/10ths of a second. A neuron can transmit between 250 and 2,500 impulses per second.

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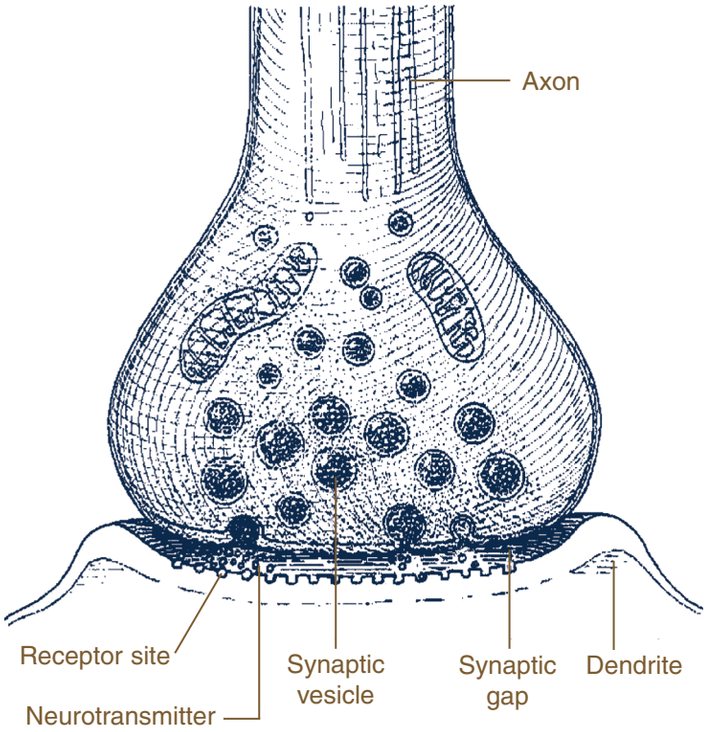

Figure 1.4 The neural impulse is carried across the synapse by chemicals called neurotransmitters that lie within the synaptic vesicles.

Neurons have no direct contact with each other. Between each dendrite and axon is a small gap of about a millionth of an inch called a *synapse* (from the Greek, meaning "to join together"). A typical neuron collects signals from others through the dendrites, which are covered at the synapse with thousands of tiny bumps, called *spines*. The neuron sends out spikes of electrical activity (impulses) through the axon to the synapse where the activity releases chemicals stored in sacs (called *synaptic vesicles*) at the end of the axon (Figure 1.4). These chemicals, called *neurotransmitters*, either excite or inhibit the neighboring neuron. More than 50 different neurotransmitters have been discovered so far. Some of the common neurotransmitters are acetylcholine, epinephrine, serotonin, and dopamine. Learning occurs by changing the synapses so that the influence of one neuron on another also changes.

A direct connection seems to exist between the physical world of the brain and the work of the brain's owner. Recent studies of neurons in people of different occupations (e.g., professional musicians) show that the more complex the skills demanded of the occupation, the more dendrites were found on the neurons. This increase in dendrites allows for more connections between neurons resulting in more sites in which to store learnings.

There are about 100 billion neurons in the adult human brain—about 16 times as many neurons as people on this planet and about the number of stars in the Milky Way. Each neuron can have up to 10 thousand dendrite branches. This means that it is possible to have up to one quadrillion (that's a one followed by 15 zeros) synaptic connections in one brain. This inconceivably large number allows the brain to process the data coming continuously from the senses; to store decades of memories, faces, and places; to learn languages; and to combine information in a way that no other individual on this planet has ever thought of before. This is a remarkable achievement for just three pounds of soft tissue!

Believe it or not, the number of potential synaptic connections in just one human brain is about 1,000,000,000,000,000.

Conventional wisdom has been that neurons were the only body cells that never regenerate. However, researchers have discovered that the adult human brain does generate neurons in at least one site—the hippocampus. This discovery raises the question of whether neurons regenerate in other parts of the brain and, if so, if it might

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be possible to stimulate them to repair and heal damaged brains, especially for the growing number of people with Alzheimer's disease. Research into Alzheimer's disease is exploring ways to stop the deadly mechanisms that trigger the destruction of neurons.

Mirror Neurons

Scientists using fMRI technology recently discovered clusters of neurons in the premotor cortex (the area in front of the motor cortex that plans movements) firing just before a person carries out a planned movement. Curiously, these neurons also fired when a person saw someone else perform the movement. For example, the firing pattern of these neurons that preceded the subject grasping a cup of coffee, was identical to the pattern when the subject saw someone else do that. Thus, similar brain areas process both the production and perception of movement. Neuroscientists believe these *mirror neurons* may help an individual to decode the intentions and predict the behavior of others. They allow us to re-create the experience of others within ourselves, and to understand others' emotions and empathize. Seeing the look of disgust or joy on other people's faces cause mirror neurons to trigger similar emotions in us. We start to feel their actions and sensations as though we were doing them.

Mirror neurons probably explain the mimicry we see in young children when they imitate our smile and many of our other movements. We have all experienced this phenomenon when we attempted to stifle a yawn after seeing someone else yawning. Neuroscientists believe that mirror neurons may explain a lot about mental behaviors that have remained a mystery. For instance, there is experimental evidence that children with autism may have a deficit in their mirror-neuron system. That would explain why they have difficulty inferring the intentions and mental state of others (Oberman et al., 2005). Researchers also suspect that mirror neurons may play a role in our ability to develop articulate speech.

Brain Fuel

Brain cells consume oxygen and glucose (a form of sugar) for fuel. The more challenging the brain's task, the more fuel it consumes. Therefore, it is important to have adequate amounts of these substances in the brain for optimum functioning. Low amounts of oxygen and glucose in the blood can produce lethargy and sleepiness. Eating a moderate portion of food containing glucose (fruits are an excellent source) can boost the performance and accuracy of working memory, attention, and motor function (Korol & Gold, 1998; Scholey, Moss, Neave, & Wesnes, 1999).

Many students (and their teachers) do not eat a breakfast with sufficient glucose, nor drink enough water during the day for healthy brain function.

Water, also essential for healthy brain activity, is required to move neuron signals through the brain. Low concentrations of water diminish the rate and efficiency of these signals. Moreover, water keeps the lungs sufficiently moist to allow for the efficient transfer of oxygen into the bloodstream.

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Many students (and their teachers, too) do not eat a breakfast that contains sufficient glucose, nor do they drink enough water during the day to maintain healthy brain function. Schools should have breakfast programs and educate students on the need to have sufficient blood levels of glucose during the day. Schools should also provide frequent opportunities for students and staff to drink plenty of water. The current recommended amount is one eight-ounce glass of water a day for each 25 pounds of body weight.

NEURON DEVELOPMENT IN CHILDREN

Neuron development starts in the embryo shortly after conception and proceeds at an astonishing rate. In the first four months of gestation, about 200 billion neurons are formed, but about half will die off during the fifth month because they fail to connect with any areas of the growing embryo. This purposeful destruction of neurons (called *apoptosis*) is genetically programmed to ensure that only those neurons that have made connections are preserved, and to prevent the brain from being overcrowded with unconnected cells. Any drugs or alcohol that the mother takes during this time can interfere with the growing brain cells, increasing the risk of fetal addiction and mental defects.

The neurons of a newborn are immature; many of their axons lack the protective myelin layer and there are few connections between them. Thus, most regions of the cerebral cortex are quiet. Understandably, the most active areas are the brainstem (body functions) and the cerebellum (movement).

The neurons in a child's brain make many more connections than those in adults. A newborn's brain makes connections at an incredible pace as the child absorbs its environment. Information is entering the brain through "windows" that emerge and taper off at various times. The richer the environment, the greater the number of interconnections that are made. Consequently, learning can take place faster and with greater meaning.

As the child approaches puberty, the pace slackens and two other processes begin: Connections the brain finds useful become permanent; those not useful are eliminated (apoptosis) as the brain selectively strengthens and prunes connections based on experience. This process continues throughout our lives, but it appears to be most intense between the ages of three and 12. Thus, at an early age, experiences are already shaping the brain and designing the unique neural architecture that will influence how it handles future experiences in school, work, and other places.

Windows of Opportunity

Windows of opportunity represent important periods in which the young brain responds to certain types of input to create or consolidate neural networks. Some windows are critical, and are called *critical periods* by pediatric researchers. For example, if even a perfect brain doesn't receive visual stimuli by the age of two, the child will be forever blind, and if it doesn't hear words by the age of 12, the person will most likely never learn a language. When these critical windows close, the brain cells assigned to those tasks may be pruned or recruited for other tasks (Diamond & Hopson, 1998).

Other windows are more plastic, but still significant. It is important to remember that learning can occur in each of the areas for the rest of our lives, even after a window tapers off. However, the

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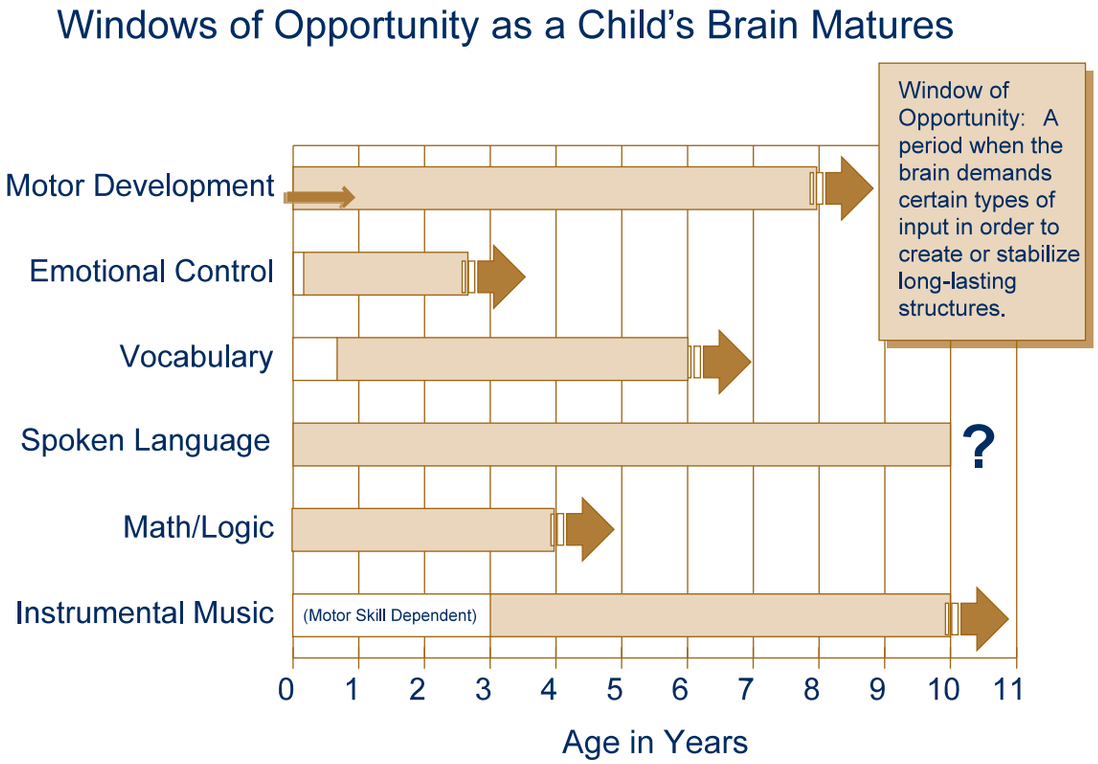

Figure 1.5 The chart shows some of the sensitive periods for learning during childhood, according to current research. Future studies may modify the ranges shown in the chart. It is important to remember that learning occurs throughout our entire life.

skill level probably will not be as high. This ability of the brain to continually change during our lifetime in subtle ways as a result of experience is referred to as *plasticity.*

An intriguing question is why the windows taper off so early in life, especially since the average life span is now over 75 years of age. One possible explanation is that these developmental spurts are genetically determined and were set in place many thousands of years ago when our life span was closer to 20 years. Figure 1.5 shows just a few of the windows which we will examine to understand their importance.

Motor Development

This window opens during fetal development. Those who have borne children remember all too well the movement of the fetus during the third trimester as motor connections and systems are consolidating. The child's ability to learn motor skills appears to be most pronounced in the first eight years. Such seemingly simple tasks as crawling and walking require complicated associations of neural networks, including integrating information from the balance sensors in the inner ear and output signals to the leg and arm muscles. Of course, a person can learn motor skills after

What is learned while a window of opportunity is opened will most likely be learned masterfully.

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the window tapers off. However, what is learned while it is open will most likely be learned masterfully. For example, most concert virtuosos, Olympic medalists, and professional players of individual sports (e.g., tennis and golf) began practicing their skills by the age of eight.

Emotional Control

The window for developing emotional control seems to be from two to 30 months. During that time, the limbic (emotional) system and the frontal lobe's rational system are evaluating each other's ability to get its owner what it wants. It is hardly a fair match. Studies of human brain growth suggest that the emotional (and older) system develops faster than the frontal lobes (Figure 1.6) (Beatty, 2001; Goldberg, 2001; Gazzaniga, Ivry, & Mangun, 2002; Luciana, Conklin, Hooper, & Yarger, 2005; Paus, 2005; Restak, 2001; Steinberg, 2005). Consequently, the emotional system is more likely to win the tug-of-war for control. If tantrums almost always get the child satisfaction when the window is open, then that is likely the method the child will use when the window tapers off. This constant emotional-rational battle is one of the major contributors to the "terrible twos." Certainly, one can learn to control emotions after that age. But what the child learned during that open window period will be difficult to change, and it will strongly influence what is learned after the window tapers off.

The struggle between the emotional and rational systems is a major contributor to the "terrible twos."

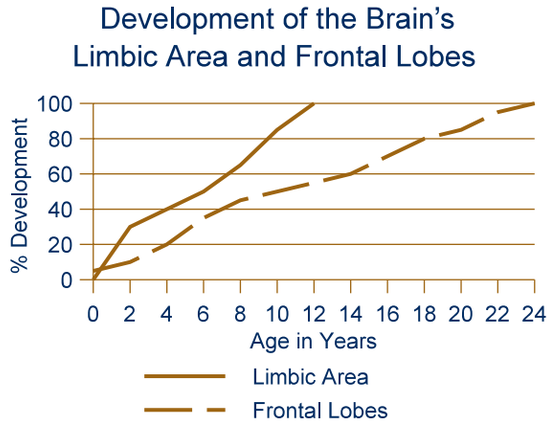

Figure 1.6 Based on research studies, this chart suggests the possible degree of development of the brain's limbic area and frontal lobes. The 10- to 12-year lag in the full development of the frontal lobes (the brain's rational system) explains why so many adolescents and young adults get involved in risky situations.

In an astonishing example of how nurturing can influence nature, there is considerable evidence confirming that how parents respond to their children emotionally during this time frame can encourage or stifle genetic tendencies. Biology is not destiny, so gene expression is not necessarily inevitable. To produce their effects, genes must be turned on. The cells on the tip of your nose contain the same genetic code as those in your stomach lining. But the gene that codes for producing stomach acid is activated in your stomach, yet idled on your nose. For example, shyness is a trait that seems to be partially hereditary. If parents are overprotective of their bashful young daughter, the toddler is likely to remain shy. On the other hand, if they encourage her to interact with other toddlers, she may overcome it. Thus, genetic tendencies toward intelligence, sociability, or schizophrenia and aggression can be ignited or moderated by parental response and other environmental influences (Reiss, Neiderheiser, Hetherington, & Plomin, 2000).

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Vocabulary

Because the human brain is genetically predisposed for language, babies start uttering sounds and babble nonsense phrases as early as the age of two months. By the age of eight months, infants begin to try out simple words like "mama" and "dada." The language areas of the brain become really active at 18 to 20 months. A toddler can learn 10 or more words per day, yielding a vocabulary of about 900 words at age three, increasing to 2,500 to 3,000 words by the age of five.

Here's testimony to the power of talk: Researchers have shown that babies whose mothers talked to them more had significantly larger vocabularies. Knowing a word is not the same as understanding its meaning. So it is crucial for parents to encourage their children to use new words in a context that demonstrates they know what the words mean. Children who know the meaning of most of the words in their large vocabulary will start school with a greater likelihood that learning to read will be easier and quicker.

Language Acquisition

The newborn's brain is not the *tabula rasa* (blank slate) we once thought. Certain areas are specialized for specific stimuli, including spoken language. The window for acquiring spoken language opens soon after birth and tapers off around the ages of 10 to 12 years. Beyond that age, learning any language becomes more difficult. The genetic impulse to learn language is so strong that children found in feral environments often make up their own language. There is also evidence that the human ability to acquire grammar may have a specific window of opportunity in the early years (Diamond & Hopson, 1998). Knowing this, it seems illogical that many schools still wait to *start* new language instruction in middle school or high school rather than in the primary grades. Chapter 5 deals in greater detail with how the brain acquires spoken language.

Mathematics and Logic

How and when the young brain understands numbers is uncertain, but there is mounting evidence that infants have a rudimentary number sense which is wired into certain brain sites at birth (Butterworth, 1999). The purpose of these sites is to categorize the world in terms of the "number of things" in a collection, that is, they can tell the difference between two of something and three of something. We drive along a road and see horses in a field. While we are noticing that they are brown and black, we cannot help but see that there are four of them. Researchers have also found that toddlers as young as two recognize the relationships between numbers as large as 4 and 5, even though they are not able to verbally label them. This research shows that fully functioning language ability is not needed to support numerical thinking (Brannon & van der Walle, 2001).

Instrumental Music

All cultures create music, so we can assume that it is an important part of being human. Babies respond to music as early as two to three months of age. A window for creating music may be open

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School districts should communicate with the parents of newborns and offer their services and resources to help parents succeed as the first teachers of their children.

at birth, but obviously neither the baby's vocal chords nor motor skills are adequate to sing or to play an instrument. Around the age of three years, most toddlers have sufficient manual dexterity to play a piano (Mozart was playing the harpsichord and composing at age four). Several studies have shown that children ages three to four years who received piano lessons scored significantly higher in spatial-temporal tasks than a group who did not get the instrumental music training. Further, the increase was long-term. Brain imaging reveals that creating instrumental music excites the same regions of the left frontal lobe responsible for mathematics and logic. See Chapter 6 for more on the effects of music on the brain and learning.

Research on how the young brain develops suggests that an enriched home and preschool environment during the early years can help children build neural connections and make full use of their mental abilities. Because of the importance of early years, I believe school districts should communicate with the parents of newborns and offer their services and resources to help parents succeed as the first teachers of their children. Such programs are already in place on a statewide basis in Michigan, Missouri, and Kentucky, and similar programs sponsored by local school districts are springing up elsewhere. But we need to work faster toward achieving this important goal.

THE BRAIN AS A NOVELTY SEEKER

Part of our success as a species can be attributed to the brain's persistent interest in novelty, that is, changes occurring in the environment. The brain is constantly scanning its environment for stimuli. When an unexpected stimulus arises—such as a loud noise from an empty room—a rush of adrenalin closes down all unnecessary activity and focuses the brain's attention so it can spring into action. Conversely, an environment that contains mainly predictable or repeated stimuli (like some classrooms?) lowers the brain's interest in the outside world and tempts it to turn within for novel sensations.

Environmental Factors That Enhance Novelty

We often hear teachers remark that students are more different today in the way they learn than ever before. They seem to have shorter attention spans and bore easily. Why is that? Is there something happening in the environment of learners that alters the way they approach the learning process?

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The Environment of the Past

The home environment for many children several decades ago was quite different from that of today. For example,

- The home was quieter—some might say boring compared to today.
- Parents and children did a lot of talking and reading.
- The family unit was more stable and ate together, and the dinner hour was an opportunity for parents to discuss their children's activities as well as reaffirm their love and support.
- If the home had a television, it was in a common area and controlled by adults. What children watched could be carefully monitored.
- School was an interesting place because it had television, films, field trips, and guest speakers. Because there were few other distractions, school was an important influence in a child's life and the primary source of information.
- The neighborhood was also an important part of growing up. Children played together, developing their motor skills as well as learning the social skills needed to interact successfully with other children in the neighborhood.

The Environment of Today

In recent years, children have been growing up in a very different environment.

- Family units are not as stable as they once were. Single-parent families are more common, and children have fewer opportunities to talk with the adults who care for them. Their dietary habits are changing as home cooking is becoming a lost art.
- They are surrounded by media: cell phones, multiple televisions, movies, computers, video games, e-mail, and the Internet. Teens spend nearly 17 hours a week on the Internet and nearly 14 hours a week watching television (Guterl, 2003).
- Many 10- to 18-year olds can now watch television and play with other technology in their own bedrooms, leading to sleep deprivation. Furthermore, with no adult present, what kind of moral compass is evolving in the impressionable pre-adolescent mind as a result of watching programs containing violence and sex on television and the Internet?
- They get information from many different sources beside school.
- The multi-media environment divides their attention. Even newscasts are different. In the past, only the reporter's face was on the screen. Now, the TV screen I am looking at is loaded with information. Three people are reporting in from different corners of the world. Additional non-related news is scrolling across the bottom, and the stock market averages are changing in the lower right-hand corner just below the local time and temperature. For me, these tidbits are distracting and are forcing me to split my attention into several components. I find myself missing a reporter's comment because a scrolling item caught my attention. Yet, children have become accustomed to these information-rich and rapidly changing messages.

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They can pay attention to several things at once, but they do not go into any one thing in depth.

- They spend much more time indoors with their technology, thereby missing outdoor opportunities to develop gross motor skills and socialization skills necessary to communicate and act personally with others. One unintended consequence of spending so much time indoors is the rapid rise in the number of overweight children and adolescents, now more than 15 percent of 6- to 19-year olds.
- Young brains have responded to the technology by changing their functioning and organization to accommodate the large amount of stimulation occurring in the environment. By acclimating itself to these changes, brains respond more than ever to the unique and different—what is called *novelty*. There is a dark side to this increased novelty-seeking behavior. Some adolescents who perceive little novelty in their environment may turn to mind-altering drugs, such as ecstasy and amphetamines, for stimulation. This drug dependence can further enhance the brain's demand for novelty to the point that it becomes unbalanced and resorts to extremely risky behavior.
- Their diet contains increasing amounts of substances that can affect brain and body functions. Caffeine is a strong brain stimulant, considered safe for most adults in small quantities. But caffeine is found in many of the foods and drinks that teens consume daily. Too much caffeine causes insomnia, anxiety, and nausea. Some teens can also develop allergies to aspartame (an artificial sugar found in children's vitamins and many "lite" foods) and other food additives. Possible symptoms of these allergic reactions include hyperactivity, difficulty concentrating, and headaches (Bateman, et al., 2004; Millichap & Yee, 2003).

When we add to this mix the changes in family lifestyles and the temptations of alcohol and drugs, we can realize how very different the environment of today's child is from that of just 15 years ago.

Have Schools Changed With the Environment?

Many educators are recognizing the characteristics of the new brain, but they do not always agree on what to do about it. Granted, teaching methodologies are changing, new technologies are being used, and teachers are even introducing pop music and culture to supplement traditional classroom materials. But schools and teaching are not changing fast enough. In high schools, lecturing continues to be the main method of instruction, primarily because of the vast amount of required curriculum material and the pressure of increased accountability and testing. Students remark that school is a dull, nonengaging environment that is much less interesting than what is available outside school.

As we continue to develop a more scientifically based understanding about today's novel brain, we must decide how this new knowledge should change what we do in schools and classrooms.

Despite the recent efforts of educators to deal with this new brain, many high school students still do not feel challenged. In a 2004 survey of 90,000 high school students in 26 states, 55 percent of students said they devoted three hours a week or less to classroom preparation, but 65 percent

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reported getting grades of A or B. Survey administrators reported that many students said they did not feel challenged to do their best work and thus were more likely to spend time doing personal reading online than doing assigned reading for their classes (HSSSE, 2005).

In another survey of 10,500 high school students, conducted by the National Governors Association, more than one-third of the students said their school had not done a good job challenging them to think critically and analyze problems. About 11 percent said they were thinking of dropping out of school. Over one-third of this group said they were leaving because they were "not learning anything" (NGA, 2005).

The Gallup Poll asked nearly 800 students ages 13 to 17 in an online survey to select three adjectives that best described how they felt about school. Half the students chose "bored" and 42 percent chose "tired" (Gallup, 2004a).

Clearly, we educators have to rethink now, more than ever, how we must adjust schools to accommodate and maintain the interest of this new brain. As we continue to develop a more scientifically based understanding about today's novel brain and how it learns, we must decide how this new knowledge should change what we do in schools and classrooms.

What's Coming Up?

Now that we have reviewed some basic parts of the brain, and discussed how the brain of today's student has become acclimated to novelty, the next step is to look at a model of how the brain processes new information. Why do students remember so little and forget so much? How does the brain decide what to retain and what to discard? The answers to these and other important questions about brain processing will be found in the next chapter.

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PRACTITIONER'S CORNER

Fist for a Brain

This activity shows how you can use your fists to represent the human brain. Metaphors are excellent learning and remembering tools. When you are comfortable with the activity, share it with your students. They are often very interested in knowing how their brain is constructed and how it works. This is a good example of novelty.

1. Extend both arms with palms open and facing down and lock your thumbs.

2. Curl your fingers to make two fists.

3. Turn your fists inward until the knuckles touch.

4. While the fists are touching, pull both toward your chest until you are looking down on your knuckles. This is the approximate size of your brain! Not as big as you thought? Remember, it's not the size of the brain that matters; it's the number of connections between the neurons. Those connections form when stimuli result in learning. The thumbs are the front and are crossed to remind us that the left side of the brain controls the right side of the body, and the right side of the brain controls the left side of the body. The knuckles and outside part of the hands represent the **cerebrum** or thinking part of the brain.

5. Spread your palms apart while keeping the knuckles touching. Look at the tips of your fingers, which represent the **limbic** or emotional area. Note how this area is buried deep within the brain, and how the fingers are mirror-imaged. This reminds us that most of the structures of the limbic system are duplicated in each hemisphere.

6. The wrists are the **brainstem** where vital body functions (such as body temperature, heart beat, blood pressure) are controlled. Rotating your hands shows how the brain can move on top of the spinal column, which is represented by your forearms.

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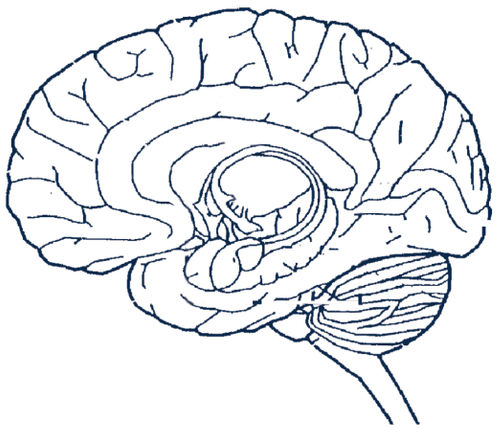
PRACTITIONER'S CORNER

Review of Brain Area Functions

Here is an opportunity to assess your understanding of the major brain areas. Write in the table below your own key words and phrases to describe the functions of each of the eight brain areas. Then draw an arrow to each brain area on the diagram below and label it.



Cerebrum:
Frontal Lobe:
Thalamus:
Hypothalamus:
Hippocampus:
Amygdala:
Cerebellum:
Brainstem:

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PRACTITIONER'S CORNER

Using Novelty in Lessons

Using novelty does *not* mean that the teacher needs to be a stand-up comic or the classroom a three-ring circus. It simply means using a varied teaching approach that involves more student activity. Here are a few suggestions for incorporating novelty in your lessons.

- **Humor.** There are many positive benefits that come from using humor in the classroom at *all* grade levels. See the **Practitioner's Corner** in Chapter 2 (p. 63) which suggests guidelines and beneficial reasons for using humor.

- **Movement.** When we sit for more than twenty minutes, our blood pools in our seat and in our feet. By getting up and moving, we recirculate that blood. Within a minute, there is about 15 percent more blood in our brain. We do think better on our feet than on our seat! Students sit too much in classrooms, especially in secondary schools. Look for ways to get students up and moving, especially when they are verbally rehearsing what they have learned.

- **Multi-Sensory Instruction.** Today's students are acclimated to a multi-sensory environment. They are more likely to give attention if there are interesting, colorful visuals and if they can walk around and talk about their learning.

- **Quiz Games.** Have students develop a quiz game or other similar activity to test each other on their knowledge of the concepts taught. This is a common strategy in elementary classrooms, but underutilized in secondary schools. Besides being fun, it has the added value of making students rehearse and understand the concepts in order to create the quiz questions and answers.

- **Music.** Although the research is inconclusive, there are some benefits of playing music in the classroom at certain times during the learning episode. See the **Practitioner's Corner** in Chapter 6 (p. 235) on the use of music.

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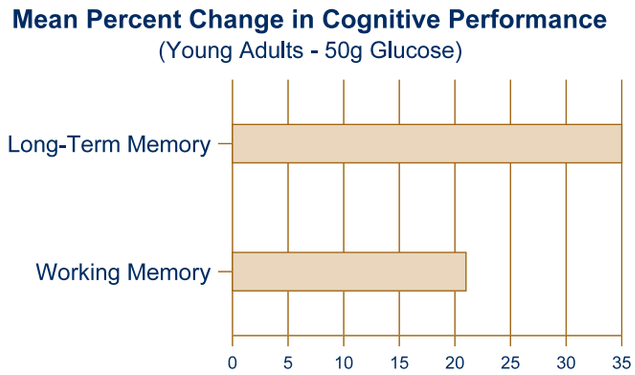
PRACTITIONER'S CORNER

Preparing the Brain for Taking a Test

Taking a test can be a stressful event. Chances are your students will perform better on a test of cognitive or physical performance if you prepare the brain by doing the following:

- **Exercise.** Get the students up to do some exercise for just two minutes. Jumping jacks are good because the students stay in place. Students who may not want to jump up and down can do five brisk round trip walks along the longest wall of the classroom. The purpose here is to get the blood oxygenated and moving faster.

- **Fruit.** Besides oxygen, brain cells also need glucose for fuel. Fruit is an excellent source of glucose. Students should eat about 2 ounces (over 50 grams) of fruit. Dried fruit, such as raisins, is convenient. Avoid fruit drinks as they often contain just fructose, a fruit sugar that does not provide immediate energy to cells. The chart below shows how just 50 grams of glucose increased long-term memory recall in a group of young adults by 35 percent and recall from working memory by over 20 percent (Korol & Gold, 1998).



- **Water.** Wash down the fruit with an 8-ounce glass of water. The water gets the sugar into the bloodstream faster and hydrates the brain.

Wait about five minutes after these steps before giving the test. That should be enough time for the added glucose to fire up the brain cells. The effect lasts for only about 30 minutes, so the steps need to be repeated periodically for longer tests.

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Chapter 1—Basic Brain Facts

Key Points to Ponder

Jot down on this page key points, ideas, strategies, and resources you want to consider later. This sheet is your personal journal summary and will help to jog your memory.